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14. ABSTRACT

[1] Defense Meteorological Satellite Program (DMSP) spacecraft at 840 km observe a 27-day variation in plasma density and temperature at all subauroral latitudes. At the peak of the solar cycle, evening-sector variations are $\sim40-50\%$ in plasma density and $\sim5-10\%$ in electron temperature. The percent of variation decreases with decreasing solar activity to or below the threshold of detectability for the DMSP sensors. We compare in situ densities with simultaneous observations of total electron content but find that similar variations are not present in a consistent manner. Thus we conclude that the variations exist mostly as topside phenomena. However, comparisons with variations in the radio flux at 10.7 cm ($F_{10.7}$), a standard proxy for solar EUV, indicate that the topside variations are driven by the solar EUV flux. When compared with the variations of several alternative proxies for the solar EUV flux, we find that only one of them correlates better than $F_{10.7}$. Because the topside ionosphere couples with the plasmasphere, we suggest that similar 27-day variations should appear in plasmaspheric parameters.

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The 27-day variations of plasma densities and temperatures in the topside ionosphere

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[1]   Defense Meteorological Satellite Program (DMSP) spacecraft at 840 km observe a 27-day variation in plasma density and temperature at all subauroral latitudes. At the peak of the solar cycle, evening-sector variations are ~40–50% in plasma density and ~5–10% in electron temperature. The percent of variation decreases with decreasing solar activity to or below the threshold of detectability for the DMSP sensors. We compare in situ densities with simultaneous observations of total electron content but find that similar variations are not present in a consistent manner. Thus we conclude that the variations exist mostly as topside phenomena. However, comparisons with variations in the radio flux at 10.7 cm ($F_{10.7}$), a standard proxy for solar EUV, indicate that the topside variations are driven by the solar EUV flux. When compared with the variations of several alternative proxies for the solar EUV flux, we find that only one of them correlates better than $F_{10.7}$. Because the topside ionosphere couples with the plasmasphere, we suggest that similar 27-day variations should appear in plasmaspheric parameters.   *INDEX TERMS:* 2481 Ionosphere: Topside ionosphere; 2443 Ionosphere: Midlatitude ionosphere; 2415 Ionosphere: Equatorial ionosphere; 2479 Ionosphere: Solar radiation and cosmic ray effects; *KEYWORDS:* topside ionosphere, midlatitude ionosphere, solar EUV, ionospheric structure, ionospheric models, DMSP

1. Introduction

[2] As part of the daily specification of space weather, spacecraft of the Defense Meteorological Satellite Program (DMSP) monitor the topside ionospheric plasmas. Since there are insufficient observations to specify the global ionosphere, models and climatologies are employed to extrapolate across observational gaps. Long-term and continuous measurements of topside plasmas available from DMSP spacecraft are invaluable for improving these models and climatologies. In a preliminary survey, *Rich and Sultan* [2000] noted that the ion density varied with a period of roughly 27 days, the synodical rotation period of the Sun, but they did not describe the variation in detail. Since the ionospheric plasma is created by extreme ultraviolet (EUV) radiation from the Sun which varies as bright regions rotate into and out of view of the Earth, the plasma density variation is probably driven by variations in the EUV flux reaching the Earth. Unfortunately, long-time series of EUV measurements do not exist for the period of DMSP plasma measurement, 1987 to current. However, long-time series for EUV proxies are readily available. The purpose of this report is to demonstrate that variations of topside plasma densities and temperatures correlate with those of EUV proxies. We then reverse the correlation to identify the proxies that correlate best with the topside plasma variability.

[3] We note that 27-day effects show up weakly or not at all in many ionospheric plasma data sets and, at best, are very weak features of ionospheric models. An example of such a data set is given below. We suggest that the effect is much more pronounced at topside altitudes than in the *E* and *F* layers of the ionosphere and discuss some possible causes of this difference.

2. Data Sources

[4] DMSP spacecraft are in polar, Sun-synchronous orbits. Since 1987, they carry an instrumentation package to monitor the behavior of thermal plasma at the constant geocentric altitude of ~848 km. This instrument package has been described by *Rich* [1994] and *Rich and Hairston* [1994]. The spacecraft of the DMSP series are designated with the letter F and the flight number. The F8 spacecraft was launched in June 1987 carrying the first of the current series of in situ plasma monitors. The orbital planes of spacecraft F8, F11, and F13 are near the 0600–1800 local time (LT) meridian. Spacecraft F9, F10, F12, F14, and F15 are in orbit planes between 0800–2000 and 1030–2230 LT meridians. In this paper, data from the three dawn-dusk and the five evening-sector spacecraft will be treated as two individual series.

[5] This paper reports on measurements of in situ ion densities summed over all species (hereafter, referred to as

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the total ion density or N_i), as well as the temperatures of ambient electrons (T_e) and oxygen ions (T_{O^+}). While the plasma monitor can separate the density of O^+ ions from those of light ions (mostly H^+ with some He^+ ions), we ignore this capability since the total ion density is unaffected by changes in composition.

[6] The nearly constant local time of DMSP orbital planes makes their ionospheric measurements unique for each spacecraft. Time series from any one set of DMSP data are unaffected by local time variations that can dramatically affect plasma characteristics. This constancy in LT allows other drivers of the plasma characteristics to be more noticeable.

[7] The plasma monitor measures N_i in the range of 10^2 to 10^6 cm^{-3}. At magnetic latitudes equatorward of the auroral zones, N_i is seldom less than 10^4 and only falls below 10^3 cm^{-3} inside plasma bubbles. Near the magnetic equator, $N_i > 10^6$ cm^{-3} in a very limited set of observations [*Hanson and Urquhart*, 1994]. In such cases, diagnostic output from the ion drift meter allows estimates of N_i up to 2×10^6 cm^{-3}.

[8] The plasma monitor can measure T_e and T_{O^+} in the range of 500° to 8000° K when the plasma density is between 10^3 and 10^6 cm^{-3}. The technique for measuring temperature requires that the plasma density remain relatively constant over a 4-s measurement cycle. These criteria are met for almost all observations at midlatitudes and low latitudes but are often violated at high latitudes.

[9] Latitudes given in this paper are the corrected geomagnetic latitudes of the subsatellite location. Therefore a position with a magnetic latitude of 0° is on a field line that has a magnetic latitude of 15° to 20° when traced to the ground.

[10] The observed radio flux at a wavelength of 10.7 cm ($F_{10.7}$) at local noon is a standard proxy for the flux of EUV radiation reaching the Earth. Prior to May 1991, it was measured at 1700 UT at Ottawa, Ontario, Canada. Since June 1991, it has been measured at 2000 UT at Penticton, British Columbia, Canada. $F_{10.7}$ is the primary EUV proxy used in this paper and other similar correlation studies. It is well known that $F_{10.7}$ is not a perfect EUV proxy. In particular, some studies suggest that daily variations of the EUV flux are less than the daily variations of $F_{10.7}$. Since we are comparing the $F_{10.7}$ variations with the topside plasma variations to determine whether or not there is a correlation, this deficiency in the daily variation of the $F_{10.7}$ index does not affect our conclusions.

3. Discussion

3.1. Variation of Topside Ionospheric Plasma With Daily Variations in EUV

[11] One way of looking at data from DMSP plasma monitors is to survey the daily variations of plasma parameters. These surveys reveal variations with a period of ~27 days. The variations appear at all latitudes equatorward of the auroral oval and midlatitude trough. The variations are most noticeable in the in situ plasma density (N_i). The magnitude of change (δN_i) varies with $\overline{N_i}$ (= the running 27-day average of N_i for a given magnetic latitude and magnetic local time). When expressed as a percentage of $\overline{N_i}$ (or $\delta N_i/\overline{N_i}$), the magnitude is roughly

constant for all latitudes and all observed local times. Figure 1 shows the percentage variations of N_i at 30°N magnetic latitude plotted as a function of the day of the year for 1999. Each plot in Figure 1 shows one of the four local time sectors sampled by the DMSP spacecraft. For comparison, the dashed lines in the bottom plots of Figure 1, indicate variations of $F_{10.7}$ over the year. The 27-day variations of N_i are approximately in phase with the 27-day variations in $F_{10.7}$. Note that the period of $\delta F_{10.7}$ is not exactly 27 days since the source of the EUV radiation will be at different solar latitudes at different times and the rotation period of the Sun varies with latitude. Also, there are times when the phase of $\delta F_{10.7}$ changes because of the dimming of one dominant source region and the brightening of another. When there is a period or phase change in $\delta F_{10.7}$, a similar period or phase shift in $\delta N_i/\overline{N_i}$ is anticipated. One such phase shift occurred in the last quarter of 1999.

[12] We have investigated the degree to which $\delta N_i/\overline{N_i}$ variations are in phase with the $\delta F_{10.7}$ variations. We computed the linear correlation between daily values of δN_i and the value of $\delta F_{10.7}$ with a lag of n days. This means that if the lag is 1, the δN_i values are correlated with the $F_{10.7}$ values ascribed to one day prior. The lag number with the highest correlation coefficient indicates the phase relationship between δN_i and $F_{10.7}$. Our analysis indicates that near the maximum in the solar cycle, the δN_i correlates best with $F_{10.7}$ with a lag of 1 or 2 days, and near the minimum in the solar cycle, the δN_i correlates best with $F_{10.7}$ with a lag of zero days. There is a lag of 8 hours built into our analysis because we have averaged the N_i data over a UT day. Thus our N_i values have an effective time tag of 12 hours UT and the time tag for $F_{10.7}$ is 20 hours UT. Even with this 8-hour difference, our results at solar maximum suggest that the ionization densities in the topside ionosphere are related to solar EUV radiation absorbed in the lower thermosphere and ionosphere a day or two earlier.

[13] We have computed the linear correlation coefficients between $\delta N_i/\overline{N_i}$ and $\delta F_{10.7}/\overline{F_{10.7}}$. The result for the 1999 data shown in Figure 1 is 0.66. The correlation varies considerably over the solar cycle. Figure 2 plots all of the N_i (third plot) and $\delta N_i/\overline{N_i}$ (fourth plot) at the magnetic equator and 1800 LT for the lifetimes of the DMSP topside plasma monitors. The top plot indicates the daily averages of $F_{10.7}$. The magnetic equator was chosen for this plot to minimize summer/winter variations in the ionospheric data. The 1800 LT sector was chosen to avoid disturbances that occur in the postsunset ionosphere.

[14] While the average value of $F_{10.7}$ varied by a factor of 4 over the past solar cycle, the topside density monitored by DMSP varied by a factor of 40. Also shown in Figure 2 are the percentage variations of $F_{10.7}$ and N_i. It is clear that $\delta F_{10.7}$ and δN_i decreased from maxima to minima over the solar cycle. As the magnitude of the variations decreased, the percentage variations also decreased.

[15] The bottom plot of Figure 2 shows the linear correlation coefficient between the percentage changes in $F_{10.7}$ and N_i. Each coefficient was computed by using a year's worth of data centered on a given day. Since there are gaps in the DMSP data set, the correlation was still computed even if 35 days of data or less were missing. If more than 35 days
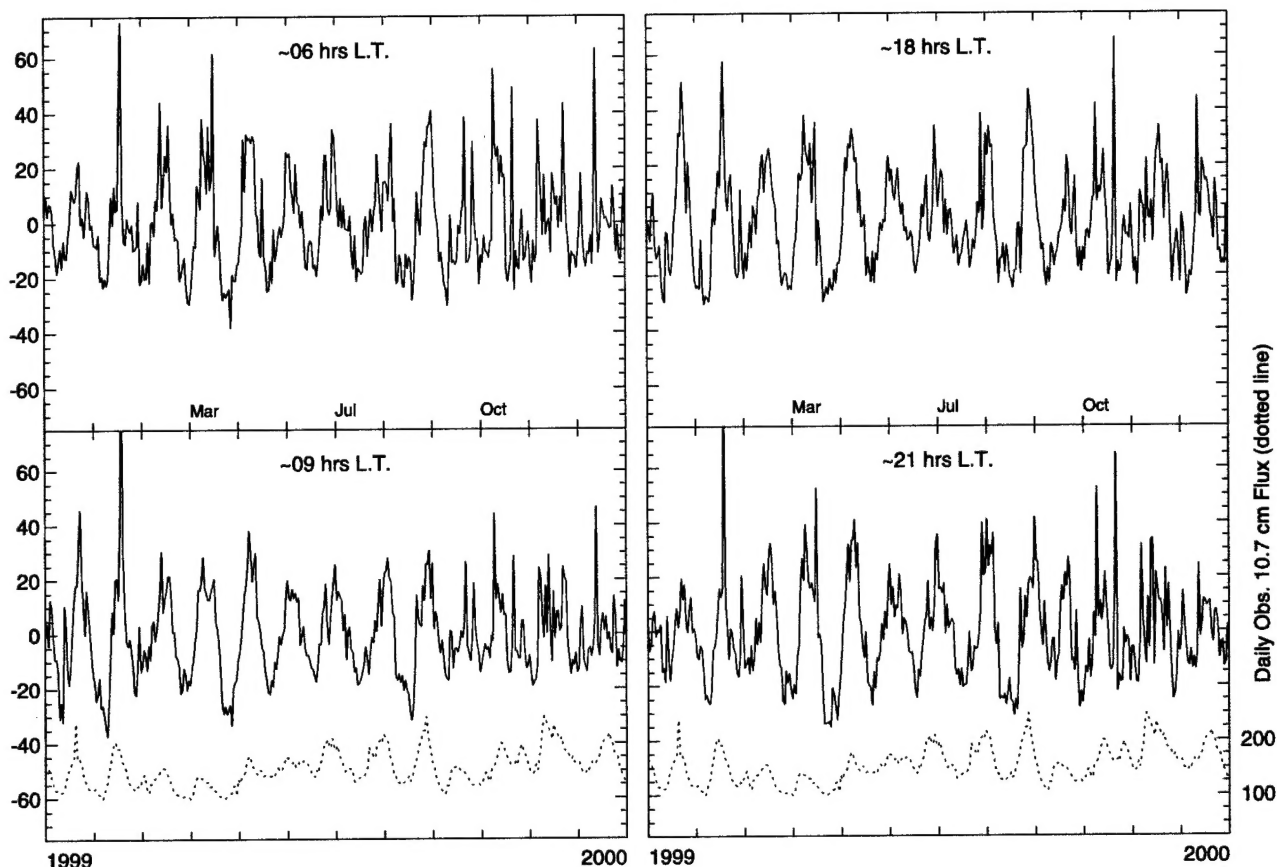
Percent Variation of Daily Ni vs. 27 day Avg Ni at 30 deg N. Mag.

Figure 1. Each plot shows the percentage by which the daily averaged, in situ total ion density at 30°N magnetic latitude varies from the 27-day average of this value during 1999. Each plot shows a different local time (LT). At the bottom of the 0900 and 2100 LT plots, the daily value of the observed 10.7-cm radio flux is shown with the scale on the right side of the 21-hour plot.

were missing, then no correlation was computed. For this computation, no DMSP data were removed because of other conditions such as high geophysical activity. If we had removed data on geophysically disturbed days, represented by high value of the Kp index, the correlation would be higher than shown. The dashed line drawn at the 0.4 level signifies the level at which we have a reasonable confidence of meaningful correlation.

[16] Electron temperatures are compared with $F_{10.7}$ in Figure 3. The top two plots of Figure 3 show the same $F_{10.7}$ information given in the top two plots of Figure 2. The next three plots show the electron temperature (T_e). There are more gaps in T_e than N_i because of sensor problems on DMSP F8 and F11. There are enough data available to state that during the minimum of the solar cycle, there is no apparent correlation between the variations in electron temperature and $F_{10.7}$. At the maximum of the solar cycle, there is a T_e variation of ~5% that is related to variations in $F_{10.7}$. The correlation coefficient is barely above our 0.4 threshold for confidence due to non-$F_{10.7}$-related variations at or above the 5% variation level. Various statistical methods could be used to improve the correlation, but the basic fact would remain that there is a correlation at the maximum in the solar cycle. During the minimum in the solar cycle, there may be an $F_{10.7}$-related variation that is

well below the 5% variation level (perhaps 2%) that cannot be separated from the other variations in T_e.

3.2. Comparison With Other EUV Proxies

[17] It is widely conceded that the 10.7 cm solar radio flux is not a perfect proxy for the solar EUV radiation. Other parameters have been suggested as better proxies. We compare some of these alternative proxies to determine if they are better at predicting the 27-day variation in the ion density observed at 840 km altitude. If they are, then they might be a better proxy for the prediction of other ionospheric and thermospheric parameters. Figure 4 plots the regression coefficient for $F_{10.7}$ versus $\log_{10}N_i$ as a function of magnetic latitude for all DMSP data collected near the dusk meridian in 1989. Each bin spans 2.5° of magnetic latitude and includes all longitudes. The year 1989 was chosen because it is near the maximum of the solar cycle when density variations were more prominent and because one of the proxies mentioned below is not available for other years. The correlations were performed both for all days of the year (annotated as all Kp) and days when $Kp \leq 4+$ on the current and previous days (annotated as low Kp).

[18] $E_{10.7}$ is an EUV proxy from the SOLAR2000 program described by *Tobiska et al.* [2000]. It is computed by inserting the H Lyman α flux and the 10.7 cm flux into a set
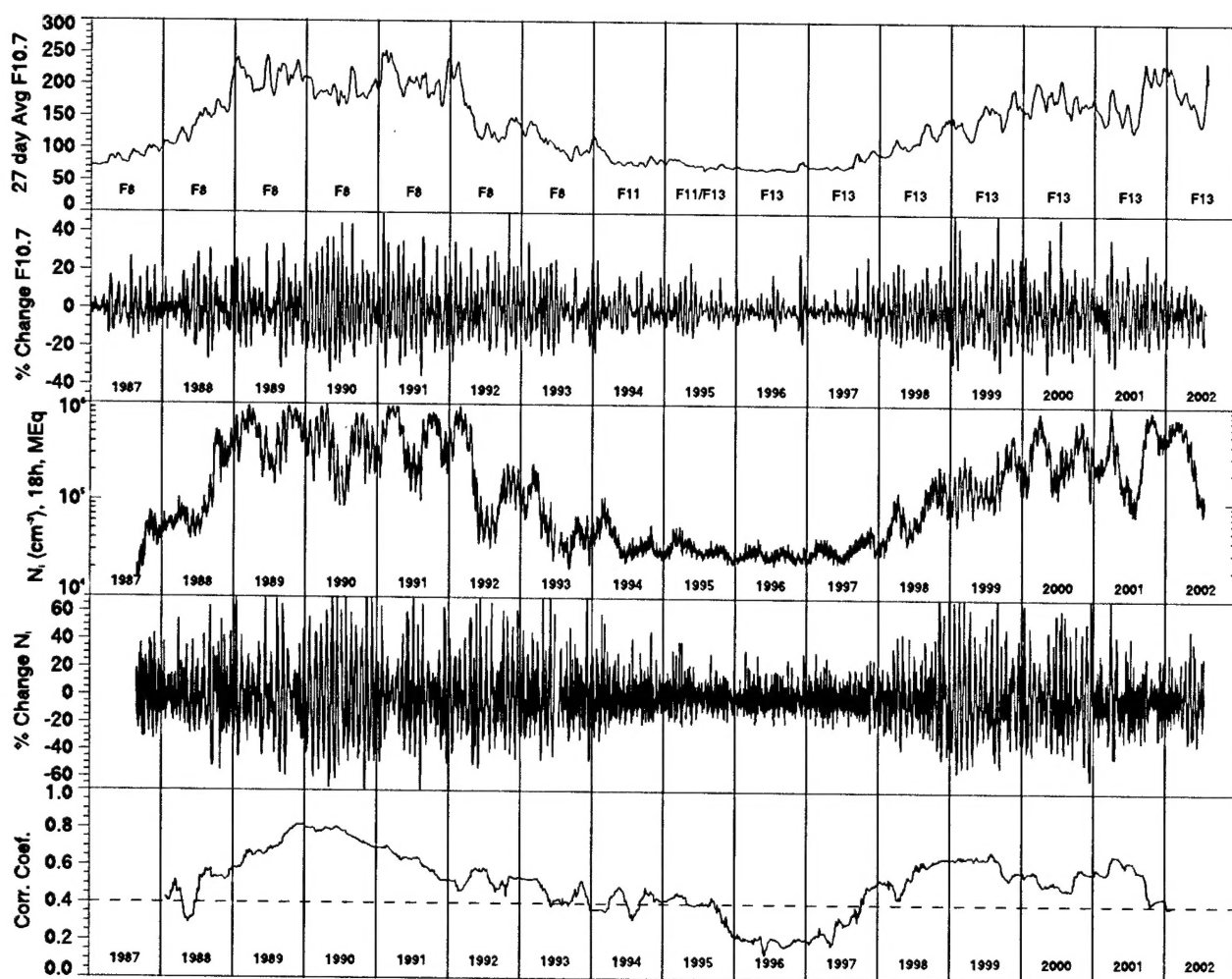
Figure 2. Comparison of $F_{10.7}$ and the total plasma density (N_i) near 1800 LT and the magnetic equator and the 10.7 cm radio flux from 1987 to 2002. The top plot shows the 27-day average of the observed 10.7 cm radio flux along with the identification of the DMSP spacecraft used to obtain the ionospheric data. The next plot shows the percentage variation of the daily value from the 27-day average. The middle plot shows the daily averaged value of N_i. The fourth plot show the percentage variation of the daily value of N_i to the 27-day average, $\overline{N}_i$. The bottom plot shows the linear correlation coefficient of second and fourth plots.

of modeling equations to obtain a proxy with the same units as $F_{10.7}$. The primary purpose of the $E_{10.7}$ index is to provide a more accurate thermospheric heating parameter, but it is generally regarded as better than $F_{10.7}$ for all uses. *Tobiska* [2001] compared $E_{10.7}$ with $F_{10.7}$ for predicting the decay of a satellite orbit and found $E_{10.7}$ superior. The major difference is that $E_{10.7}$ variations from its 27-day averages are ~50% less than those of $F_{10.7}$.

[19] Figure 5 shows the results of making the same computations as those shown in Figure 4 except that the SOLAR2000 version of the $E_{10.7}$ parameter is used instead of $F_{10.7}$. While the response in each latitude bin is slightly different, the overall result is that there is no improvement in using $E_{10.7}$ instead of $F_{10.7}$ for 1989. We have repeated the computation for other local times and other years, and the result is that $E_{10.7}$ improves the correlation by an insignificant amount (<0.05) or not at all. We conclude that $E_{10.7}$ does not improve our ability to predict N_i at 840 km.

[20] *Marcos et al.* [1998] proposed an alternative proxy based on satellite drag calculations and $F_{10.7}$ measurements.

Actual atmospheric drags of target spacecraft at altitudes between 450 and 550 km were computed. $F_{10.7}$ inputs to atmospheric density models were adjusted until the computed densities matched those obtained from the drag computations. This effective $F_{10.7}$ (denoted here as $F_{10.7}*$) can be used to compute the drag on other spacecraft with significant improvements to orbital estimations. Although *Marcos et al.* [1998] made no claims that $F_{10.7}*$ has other applications, we have used their values in the same manner as for $F_{10.7}$ and $E_{10.7}$.

[21] Figure 6 shows the results of computing the correlation coefficients between $F_{10.7}*$ and $\log_{10} N_i$ for the 1800 LT sector in 1989. By comparing Figure 6 with Figures 4 and 5, it is obvious that the drag-based $F_{10.7}*$ correlates much better with N_i than either $F_{10.7}$ or $E_{10.7}$. We repeated the comparison for other local times in 1989 and obtained similar results. Unfortunately, we cannot repeat the comparison for other years because $F_{10.7}*$ is only available publicly for 1989.

[22] *Woods et al.* [1996] described the SUSIM (Solar Ultraviolet Spectral Irradiance Monitor) index as a solar
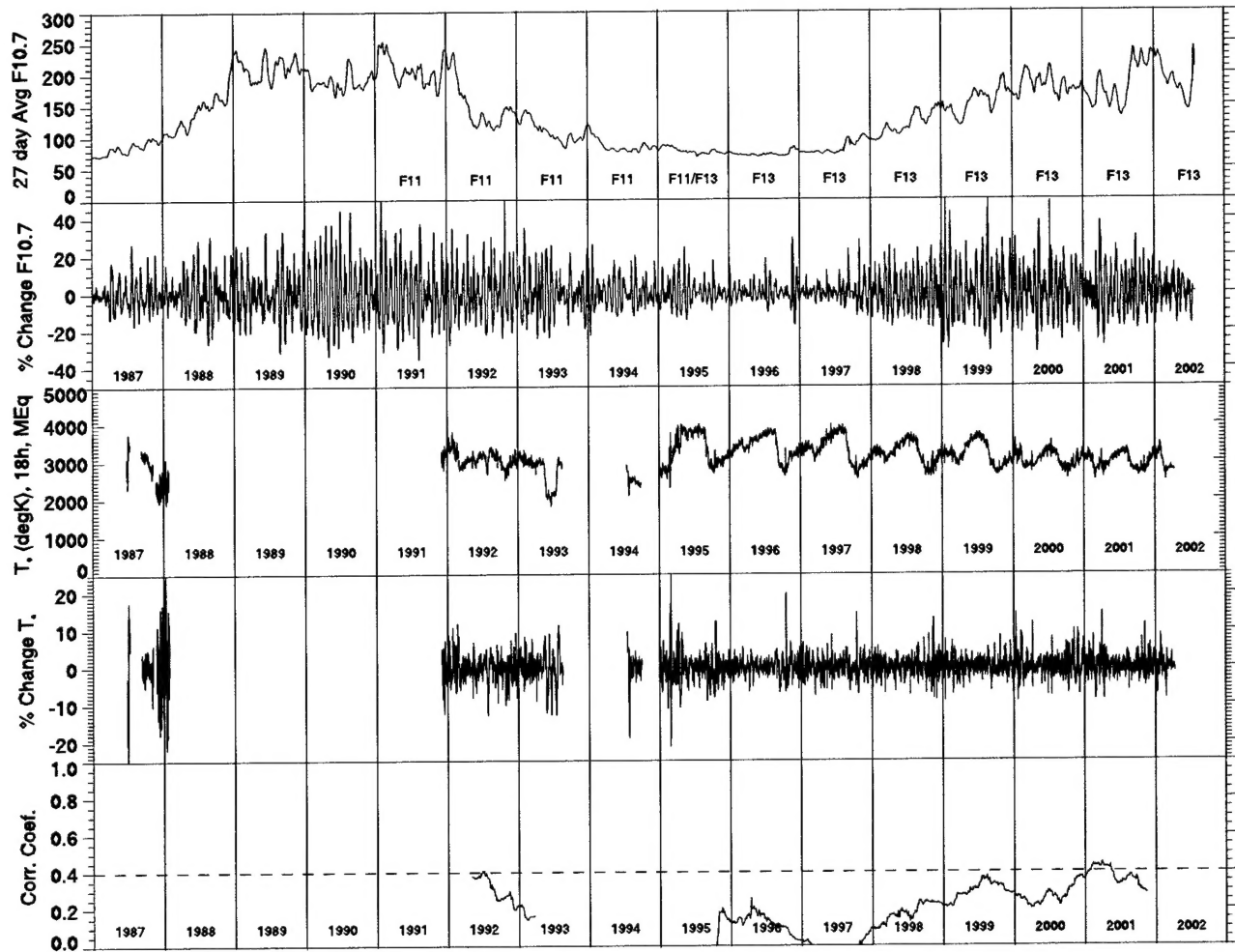
Figure 3. In a manner similar to Figure 2, the electron temperature (T_e) obtained near the magnetic equator and 18 hours LT is compared to $F_{10.7}$ from 1987 to 2002.

EUV proxy. SUSIM is based on UARS measurements of the solar Mg II line near 280 nm. While this index is not scaled to match the $F_{10.7}$, this is unimportant for computing correlations between the SUSIM Mg II index and DMSP measurements of N_i. We used version v19r2 of the SUSIM

index to compute the correlations with DMSP densities. We cannot make direct comparisons with the $F_{10.7}$* index because SUSIM started in October 1991. We compared SUSIM with the $F_{10.7}$ and $E_{10.7}$ indices for 1992 to 2000
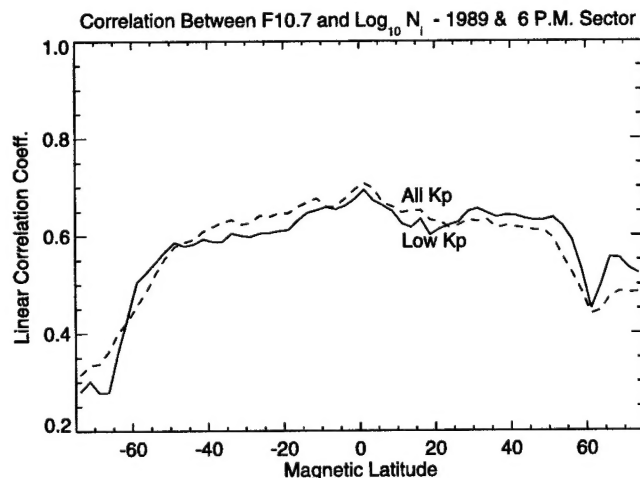

Figure 4. Correlation coefficients of $F_{10.7}$ versus $\log_{10}N_i$ for DMSP observations during 1989 in the 1800 LT sector.
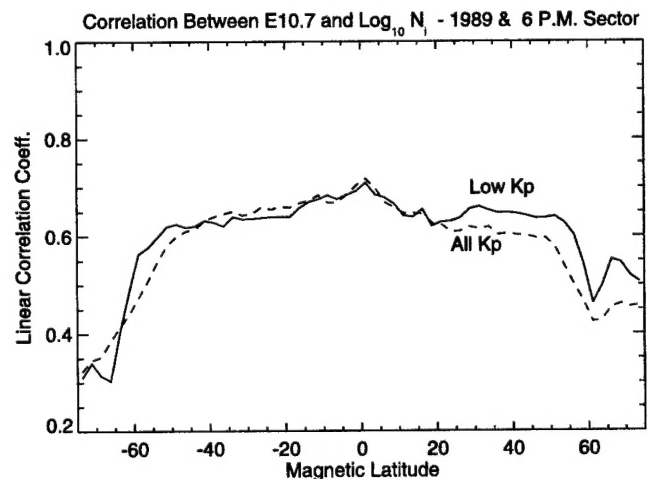

Figure 5. Correlation coefficients of $E_{10.7}$ (Solar2000) versus $\log_{10} N_i$ for DMSP observations during 1989 in the 1800 LT sector.

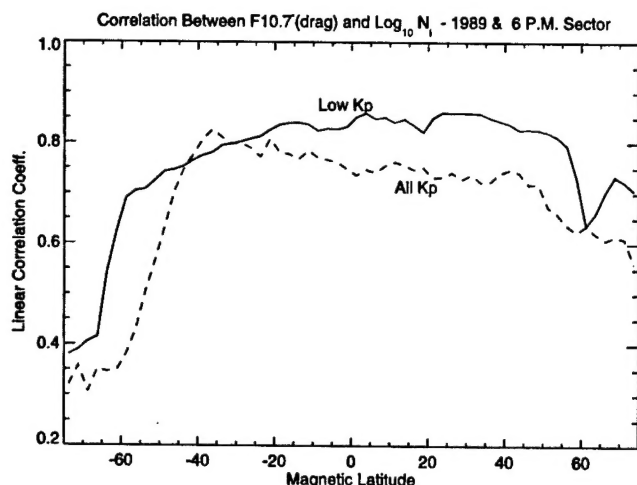Correlation Between F10.7(drag) and Log$_{10}$ N$_i$ - 1989 & 6 P.M. Sector

Figure 6. Correlation coefficients of $F_{10.7}$* (based on drag) versus $\log_{10} N_i$ for DMSP observations during 1989 in the 1800 LT sector.

and found the correlation coefficients to be the same, ±0.05, for all local times and all solar maximum and solar transition years. For the solar minimum years of 1994 to 1998, differences are larger. However, they seem random since the correlations are less than 0.40.

3.3. Comparison With Total Electron Content Measurements

[23] Since solar EUV creates the ionized gas that composes the ionosphere, it seems obvious that a daily variation in EUV should yield daily variations in the topside plasma density and temperature. However, such a correlation is not found in the data. Others have examined the plasma characteristics of the bottomside of the ionosphere and the

F region and concluded that daily variations of $F_{10.7}$ cannot be used to specify ionospheric parameters at those altitudes. For example, *Doherty et al.* [2000] looked at day-to-day variations of total electron content (TEC) measurements and concluded that $F_{10.7}$ did not improve specification algorithms. *Richards* [2001] reached a similar conclusion about estimating the density at the peak of the F_2 layer (NmF_2). Other researchers have come to similar conclusions after looking at various data sets but did not publish these null results.

[24] To illustrate why others dismissed the daily $F_{10.7}$ variations as a driver of ionospheric parameters, we re-examined the original data set used by *Doherty et al.* [2000]. Figure 7 plots the daily variations of TEC measured at Hamilton, Massachusetts, in 1990 (top) together with the daily variations of $F_{10.7}$. The 1800 LT sector was chosen for comparison with the DMSP data. The correlation coefficient for the whole year is 0.37 which falls below our criterion for a useful correlation. During individual months such as January, the correlation coefficient reached 0.66. However, during other months such as June, the correlation was close to zero. Figure 8 shows Hamilton TEC and $F_{10.7}$ variations in 1991. No correlations are apparent for either the year or individual months. Both of these examples are for solar maximum years. We conclude that the daily variations of solar EUV as represented by $F_{10.7}$ do affect TEC. However, there are other factors that affect TEC more strongly than $F_{10.7}$ and mask the effects of daily solar EUV variations.

[25] Values of TEC are dominated by contributions of N_i near the F_2 peak. They fail to show a consistent variation with $F_{10.7}$. Why then do variations of N_i at DMSP altitude correlate with $F_{10.7}$? The first possibility is a "pivot effect." While the variation in T_e observed by DMSP is much smaller than the variation in N_i, it is quite real. There may be a similar variation in the ion temperature (T_i) but it is

Hamilton TEC at 18 hrs L.T. vs F10.7 for 1990

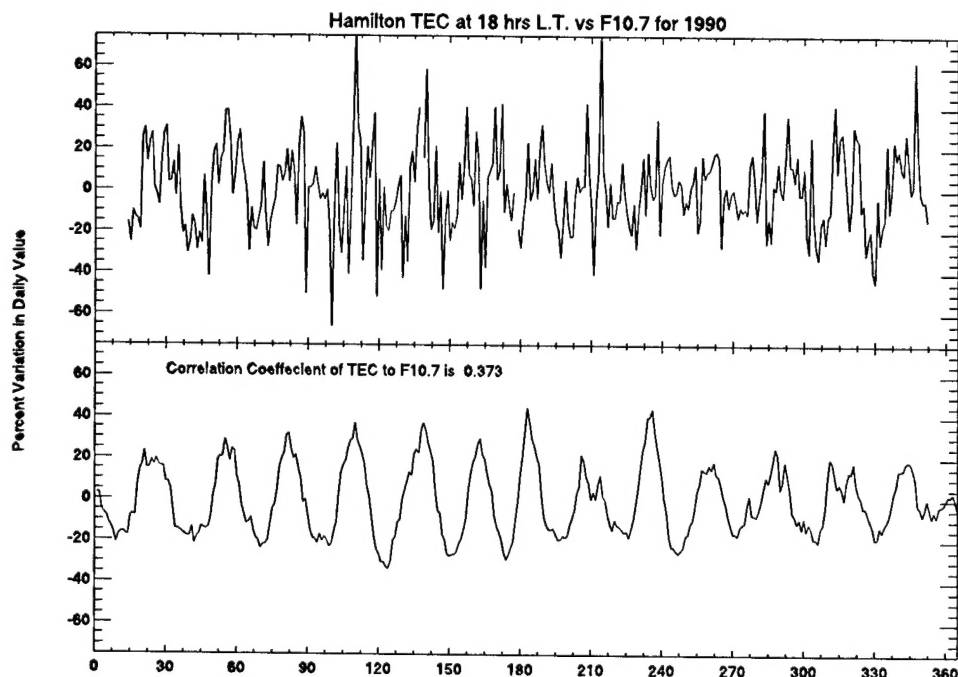Correlation Coeffecient of TEC to F10.7 is 0.373

Figure 7. The total electron content (TEC) observations from Hamilton, Massachusetts, and the $F_{10.7}$ daily values for 1990 are shown as percentage variations from their respective 27-day average.

Figure 8. The TEC observations from Hamilton, Massachusetts, and the $F_{10.7}$ daily values for 1991 are shown as percentage variations from their respective 27-day average.
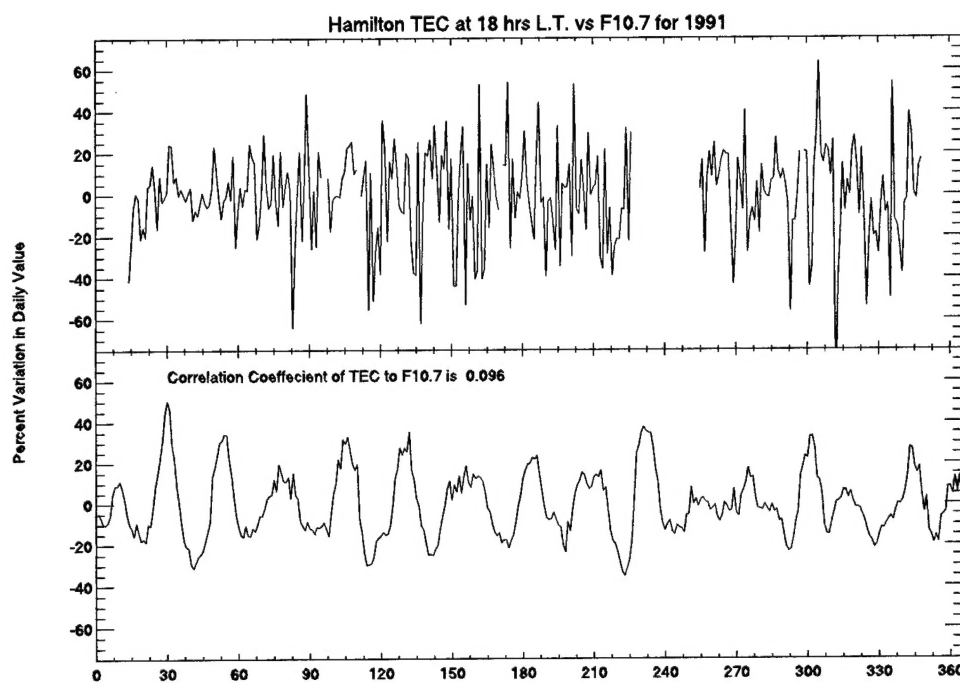
obscured by variations introduced by the data processing and other geophysical effects. This suggests that the topside scale heights vary with $F_{10.7}$. DMSP observations come from ~3 to 10 scale heights above the F_2 peak. A barely noticeable variation in density is amplified by a factor of ~3 for each scale height that the observation is made above the F_2 peak. Thus a N_i variation of 60% at the DMSP altitude might be an undetectable 3% or less N_i variation at the F_2 peak. If this is the case then simultaneous observations at some intermediate altitude, e.g., 600 km, should show intermediate variations, e.g., 20%. Observations at higher altitudes (up to the O^+/H^+ transition) should manifest larger variations. This suggests that we may even be able to detect solar cycle variations in the plasmaspheric density. Given the paucity of direct plasma density measurements in the plasmasphere, the fact that a solar cycle variability has not been reported does not mean that it does not exist. On the other hand, the ratio of $F_{10.7}$ variations to N_i at the DMSP altitude should increase as the solar cycle decreases because the number of scale heights between the F_2 peak and the DMSP altitudes increases. This does not fit the observations reported.

[26] Another possibility is that neutral density variations, driven by variations in EUV, are almost as large as those observed at DMSP. Such neutral density variations are well documented by 27-day cycles in satellite drag measurements. These variations are not noticeable in the TEC and other F_2 parameters because they are masked by other effects. For example, when the neutral density increases, the ion-neutral collision rate grows leading to increased recombination. The result could be that the height of the F_2 peak rises (but not by enough to be noticeable) and the density at the F_2 peak remains about constant. Other influences include gravity waves that affect the F_2 region and bottomside but not the topside ionosphere.

[27] The above explanations and other suggestions for the difference in the 27-day variation at 840 km and at low altitudes are not fully satisfactory. Further study will be required for a complete explanation. At this time, we can state that the 27-day variation at DMSP altitude is real and is driven by something related to the 27-day variation in EUV flux.

[28] It is interesting that the $F_{10.7}*$ alternative EUV proxy [*Marcos et al.*, 1998] is the only alternative that correlates better than the $F_{10.7}$ index for predicting N_i at the DMSP altitude. This superiority is possibly due to the fact that it is based on a parameter (the neutral density near and above the F_2 peak) that is closely related to the N_i observed by DMSP. Even if the other proxies are better at predicting the EUV flux, there are several processes required to convert the EUV energy into neutral and plasma density and temperature enhancements.

3.4. Possible Effect on Plasmasphere

[29] Since the topside ionosphere is adjacent to the bottom of the plasmasphere, there may well be a 27-day cycle in plasmaspheric parameters. As the temperature and density in the topside ionosphere increase and decrease, the outflow of plasma into the dayside plasmasphere should increase and decrease. DMSP observations show that the 27-day variation is present in regions 2 to 4 hours in LT after sunset. One way to maintain this variation is for the inflow of plasma from the plasmasphere at night to correlate with the outflow in the day sector. We know of no report about the plasmasphere that could confirm or deny this suggestion. Such a lack is due partly to the fact that no one has looked for this variation and partly to the difficulty of getting an appropriate data set for such a study. We suggest that data from spacecraft such as the Combined Release and Radiation Effects Satellite (CRRES), Polar, and others

could confirm this speculation if the data were properly separated and sorted.

4. Conclusions

[30] We have demonstrated that plasma density and temperature in the midlatitude to low-latitude ionosphere at 840 km varies with a period of ~27 days, synchronized with the same variation in the $F_{10.7}$ index. The magnitude and percentage of the 27-day variation in $F_{10.7}$ and in the topside plasma parameters wax and wane with the solar cycle.

[31] The source of the 27-day variation in the topside ionosphere must be the Sun. Since $F_{10.7}$ is a proxy for the solar EUV flux, the variations in the topside ionosphere must be driven by variations in the solar EUV flux reaching the Earth. The 27-day period is created by the rotation of the Sun carrying EUV bright regions into and out of view of the Earth.

[32] The solar EUV flux creates ionization and deposits heat in the ionosphere and thermosphere at a much lower altitude than 840 km. However, ionospheric parameters, such as TEC, which are strongly influenced by the ionosphere around the F region peak do not show a clear 27-day variation. This feature of the F region has been documented elsewhere and again in this paper. We suggest that there is a 27-day cycle in the ionization rates and heat production in the lower ionosphere, but the signatures in the plasma parameters are obscured by plasma dynamics which do not affect the topside ionosphere.

[33] Since $F_{10.7}$ is a proxy that does not perfectly track EUV flux changes, other proxies have been suggested from time to time. We tested three alternate proxies and found that the SOLAR2000 and the SUSIM proxies were no better than $F_{10.7}$ at predicting the variations in the topside ionosphere. The proxy suggested by *Marcos et al.* [1998] based on the drag of satellites is a better predictor of the variations at 840 km. Thus the thermosphere is probably responding to the same mechanisms as the topside ionosphere.

References

Doherty, P. H., J. A. Klobuchar, and J. M. Kunches, Eye on the ionosphere: The correlation between solar 10.7 cm radio flux and ionospheric range delay, *GPS Solutions*, *3*(4), 75–79, 2000.

Hanson, W. B., and A. L. Urquhart, High altitude bottomside bubbles?, *Geophys. Res. Lett.*, *21*(18), 2051–2052, 1994.

Marcos, F. A., M. J. Kendra, J. M. Griffin, J. N. Bass, D. R. Larson, and J. J. Liu, Precision low Earth orbit determination using atmospheric density calibration, *J. Astronaut. Sci.*, *46*(4), 395–409, 1998.

Rich, F., Technical description for the topside ionospheric plasma monitor (SSIES, SSIES-2 and SSIES-3) on spacecraft of the Defense Meteorological Satellite Program (DMSP), *Tech. Rep. PL-TR-94-2187*, 69 pp., Air Force Phillips Lab., Bedford, Mass., 1994.

Rich, F. J., and M. Hairston, Large-scale convection patterns observed by DMSP, *J. Geophys. Res.*, *99*(A3), 3827–3844, 1994.

Rich, F. J., and P. J. Sultan, Comparison of ion densities measured in the topside ionosphere at low latitudes and midlatitudes with calculations of ionospheric models over a full solar cycle, *Radio Sci.*, *35*(5), 1193–1204, 2000.

Richards, P. G., Seasonal and solar cycle variations of the ionospheric peak electron density: Comparison of measurement and models, *J. Geophys. Res.*, *106*(A7), 12,803–12,819, 2001.

Tobiska, W. K., Validating the solar EUV proxy, $E_{10.7}$, *J. Geophys. Res.*, *106*(A12), 29,969–29,978, 2001.

Tobiska, W. K., T. Woods, F. Eparvier, R. Viereck, L. Floyd, D. Bouwer, G. Rottman, and O. R. White, The SOLAR2000 empirical solar irradiance model and forecast tool, *J. Atmos. Terr. Phys.*, *62*, 1233–1250, 2000.

Woods, T. N., et al., Validation of the UARS solar ultraviolet irradiances: Comparison with the ATLAS 1 and 2 measurements, *J. Geophys. Res.*, *101*(D6), 9541–9569, 1996.

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